Ambiguous Air Pollution Effects of China's COVID-19 Lockdown

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Question and motivation

- Studies found COVID-19 improved global air quality. (Diffenbaugh et al., 2020; Dang and Trinh, 2020).
- Similar improvements are found in China. (Burke, 2020; NASA, 2020).

To identify the impact of COVID-19 on China's air quality, we need to consider:

1) Improving trend:
   China's air quality has been improving since 2013 (Greenstone and Schwarz, 2018; Greenstone et al., 2020).
2) Coincidence with the Spring Festival:[1]
   Spring Festival sharply reduces China's short-term air pollution (Ngo et al., 2018).
3) Air quality and pollution are multidimensional, including multiple pollutants (CO, NO_x, O_3, PM2.5, SO_2, etc.) with negative effects on human health (Zhong et al., 2017; Ebenstein et al., 2017; Currie and Neidell, 2005; Neidell, 2009; Hanna and Oliva, 2015)

[1] ≡ Lunar New Year, started on January 25, 2020

This study

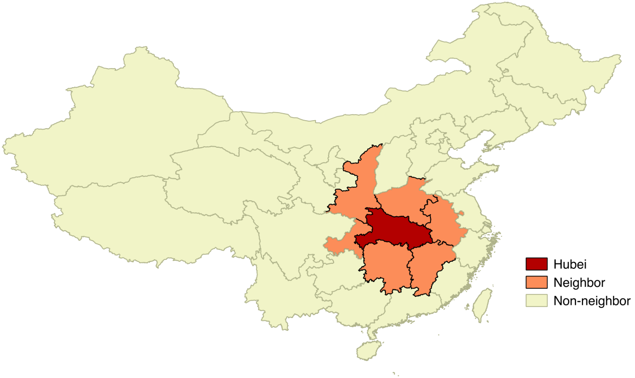
- Given the important role of the Spring Festival in air pollution and its coincidence with the COVID-19 outbreak in 2020, we use the lunar calendar rather than the Gregorian (standard) calendar.
- We use a difference-in-difference design. Air pollution in previous years relative to the start of the Festival serves as a counterfactual without COVID-19.
- Considering the large COVID-19 cluster near the epicenter, we further use a triple difference design to separate provinces near and far from the epicenter.
- We find that air quality improvement in 2020 is *smaller* in and near the epicenter, compared with other provinces. Ozone gets worse, roughly doubling in the epicenter.

Data

- Air pollution: monitor stations
  We require monitors to report complete daily data from Day -21 to Day 28 around the Spring Festival 2018-2020 (150 days).
- Weather: NCDC Global Summary of the Day
  We use average temperature, wind speed, precipitation for each province-month.
- Firm-level emissions: Continuous Emissions Monitoring Systems (CEMS)
  We require firms with complete data 10 days in the pre-period and 14 days in the post-period in both 2019 and 2020.
  Firms are from 11 provinces: 6 non-neighbor, 4 neighbor, 1 epicenter.
- COVID cases: DXY online platform
  The cumulative case counts are updated from DXY for all provinces in China every 15 minutes.

Epicenter and neighboring provinces

Province	Confirmed cases	Deaths	Cases per million people	Deaths per million people
Hubei (capital is Wuhan)	63,454	2,250	1,072.4	38.03
Neighbors	5,023	37	14.5	0.107
Non-neighbors	7,810	58	7.9	0.058



Why neighbors

Empirical specification

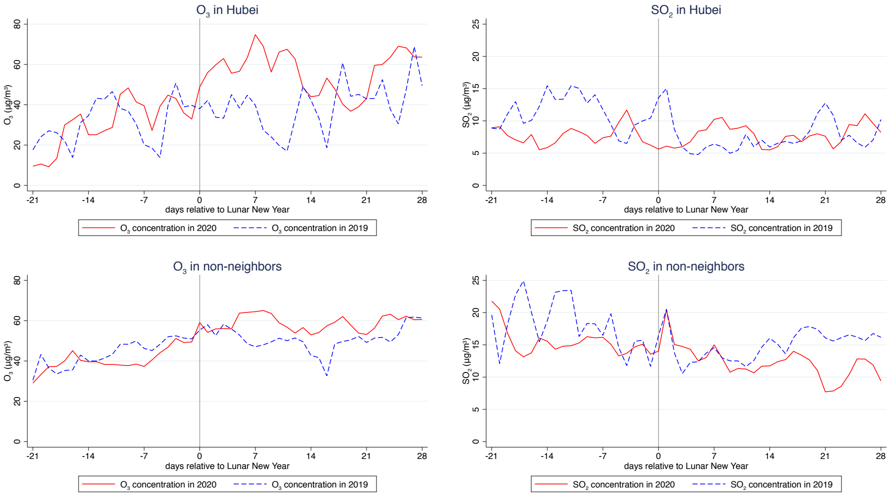
$$y_{it} = \alpha_0 + \beta_1 Post_t + \beta_2 Y2020_t + \beta_3 Post_t * Y2020_t$$
$$+\gamma_i + \tau_t + X_{it} + u_{it}$$

- y_{it}: pollution at monitor i on day t
  150 days for each monitor (Day -21 to Day 28, 2018-2020)
- $Post_t$: after Spring Festival; $Y2020_t$: year 2020
- X_{it}: weather controls
- τ_t: year 2018 dummy, day of week FEs
- γ_i: monitor FEs

$$y_{it} = \alpha_0 + \beta_1 Post_t + \beta_2 Y2020_t + \beta_3 Post_t * Y2020_t$$
$$+\beta_4 Post_t * Y2020_t * Hubei_i + \beta_5 Post_t * Hubei_i + \beta_6 Y2020_t * Hubei_i$$
$$+\gamma_i + \tau_t + X_{it} + u_{it}$$

- Only focusing on Hubei and neighbors, the single term $Hubei_i$ is absorbed by station fixed effects
- Only focusing on neighbors and non-neighbors, we replace $Hubei_i$ with $Neighbor_i$

Ozone and SO_2 in Hubei and non-neighbors



Results: Double difference

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
Panel A: All China					
Post	-0.314***	-0.174***	-0.062***	0.143***	-0.040***
	(0.006)	(0.008)	(0.010)	(0.008)	(0.004)
Post×Y2020	-0.494***	0.010	-0.252***	0.334***	-0.245***
	(0.007)	(0.009)	(0.010)	(0.008)	(0.007)
Y2020	-0.059***	-0.219***	-0.063***	-0.081***	0.032***
	(0.007)	(0.011)	(0.009)	(0.007)	(0.006)
Observations	181950	181950	180300	181200	181200
R-squared	0.584	0.633	0.409	0.374	0.423
Panel B: Hubei					
Post	-0.436***	-0.431***	-0.024	0.059**	-0.072***
	(0.024)	(0.032)	(0.029)	(0.027)	(0.023)
Post×Y2020	-0.551***	0.254***	-0.132***	0.732***	-0.130***
	(0.042)	(0.041)	(0.028)	(0.037)	(0.034)
Y2020	-0.315***	-0.187***	-0.495***	-0.111**	-0.119***
	(0.028)	(0.060)	(0.024)	(0.045)	(0.033)
Observations	5550	5700	5550	5550	5550
R-squared	0.612	0.412	0.356	0.351	0.230

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Results: Double difference (con't)

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
Panel C: Neighbors					
Post	-0.447***	-0.331***	-0.069***	0.116***	-0.029***
	(0.012)	(0.015)	(0.023)	(0.015)	(0.009)
Post×Y2020	-0.498***	0.147***	-0.262***	0.544***	-0.290***
	(0.013)	(0.018)	(0.021)	(0.017)	(0.012)
Y2020	-0.181***	-0.366***	-0.142***	-0.205***	0.006
	(0.014)	(0.023)	(0.019)	(0.015)	(0.013)
Observations	43050	43200	42600	42450	43050
R-squared	0.616	0.511	0.387	0.378	0.393
Panel D: Non-neighbors					
Post	-0.270***	-0.110***	-0.055***	0.157***	-0.041***
	(0.007)	(0.008)	(0.012)	(0.009)	(0.005)
Post×Y2020	-0.500***	-0.061***	-0.242***	0.257***	-0.235***
	(0.009)	(0.010)	(0.012)	(0.009)	(0.008)
Y2020	-0.006	-0.158***	-0.027**	-0.037***	0.046***
	(0.008)	(0.013)	(0.011)	(0.008)	(0.008)
Observations	133350	133050	132150	133200	132600
R-squared	0.581	0.661	0.402	0.369	0.431
Monitor FEs	Y	Y	Y	Y	Y
Weather	Y	Y	Y	Y	Y
Y2018	Y	Y	Y	Y	Y
DOW FEs	Y	Y	Y	Y	Y

Results: Double difference (con't)

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
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Y2018	Y	Y	Y	Y	Y
DOW FEs	Y	Y	Y	Y	Y

Results, triple difference

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
Panel A: Hubei versus Neighbors					
Post	-0.450***	-0.339***	-0.068***	0.117***	-0.033***
	(0.011)	(0.015)	(0.023)	(0.015)	(0.009)
Post×Y2020	-0.497***	0.147***	-0.260***	0.545***	-0.288***
	(0.013)	(0.018)	(0.021)	(0.018)	(0.012)
Post×Y2020×Hubei	-0.042	0.145***	0.071*	0.122***	0.170***
	(0.046)	(0.046)	(0.041)	(0.039)	(0.040)
Y2020	-0.184***	-0.373***	-0.144***	-0.196***	0.006
	(0.013)	(0.023)	(0.019)	(0.015)	(0.013)
Post×Hubei	-.0226	-.0184	-.0465	-.0163	-.0499***
	(.0166)	(.027)	(.0324)	(.0228)	(.0161)
Y2020×Hubei	-.0526**	.149**	-.134***	.0341	-.0994***
	(.0225)	(.0747)	(.0331)	(.0353)	(.0241)
Observations	48600	48900	48150	48000	48600
R-squared	0.615	0.501	0.384	0.373	0.383

Results, triple difference

	ln(NO_2)	ln(SO_2)	ln($PM_{2.5}$)	ln(O_3)	ln(CO)
Panel A: Hubei versus Neighbors					
Post	-0.450***	-0.339***	-0.068***	0.117***	-0.033***
	(0.011)	(0.015)	(0.023)	(0.015)	(0.009)
Post×Y2020	-0.497***	0.147***	-0.260***	0.545***	-0.288***
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Observations	48600	48900	48150	48000	48600
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Results, triple difference (con't)

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
Panel B: Neighbors versus Non-neighbors					
Post	-0.279***	-0.127***	-0.027**	0.160***	-0.036***
	(0.007)	(0.008)	(0.012)	(0.009)	(0.005)
Post×Y2020	-0.496***	-0.052***	-0.255***	0.256***	-0.237***
	(0.009)	(0.010)	(0.012)	(0.009)	(0.008)
Post×Y2020×Neighbor	0.005	0.201***	0.005	0.274***	-0.049***
	(0.016)	(0.021)	(0.026)	(0.019)	(0.014)
Y2020	-0.010	-0.146***	-0.032***	-0.028***	0.045***
	(0.008)	(0.013)	(0.011)	(0.008)	(0.007)
Post×Neighbor	-.132***	-.162***	-.143***	-.0566***	-.0112
	(.0106)	(.0145)	(.0239)	(.0156)	(.00874)
Y2020×Neighbor	-.162***	-.266***	-.0906***	-.204***	-.0358***
	(.0144)	(.0239)	(.0232)	(.0159)	(.013)
Observations	176400	176250	174750	175650	175650
R-squared	0.588	0.639	0.411	0.378	0.425
Monitor FEs	Y	Y	Y	Y	Y
Weather	Y	Y	Y	Y	Y
Y2018	Y	Y	Y	Y	Y
DOW FEs	Y	Y	Y	Y	Y

Results, triple difference (con't)

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
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Post	-0.279***	-0.127***	-0.027**	0.160***	-0.036***
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Y2020	-0.010	-0.146***	-0.032***	-0.028***	0.045***
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R-squared	0.588	0.639	0.411	0.378	0.425
Monitor FEs	Y	Y	Y	Y	Y
Weather	Y	Y	Y	Y	Y
Y2018	Y	Y	Y	Y	Y
DOW FEs	Y	Y	Y	Y	Y

Robustness

- Drop days with fireworks
- Use a shorter post period
- Include province-by-day trend

Robustness

Potential mechanisms

Ambient SO_2 increased in and near the epicenter:

- Industrial emissions increased
- Environmental enforcement at power plants / industrial facilities decreased due to COVID
    - CEMS reporting fell more in 2020 during Spring Festival
- Work from home changed both quantity and quality of power generation: more net use / dirty source
- COVID-related electricity use increased: hospitals, converted stadiums, new facility construction, etc.

O_3 increased in all provinces, greatest increases were in/near epicenter:

- Albedo effect: Decreased PM2.5 and albedo effect increases ozone, but the effect should be the smallest in and near the epicenter.
- Precursor effect: NO_2 decreases the most the Hubei, VOCs not observed. Large decreases in NO_x from transportation may not have decreased ozone, as NO_x not limiting production (Huang et al., 2020). Ozone from disinfectants?

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Why neighbors, not COVID-19 infection cases?

- Policy responses are not only based on infection cases. Governments shut down the Hubei provincial borders. Behavioral responses and anxiety are likely to be correlated with distance.
- Reported infections are correlated with testing capacity and intensity, which was different by province at the beginning of the outbreak.
- Infections may be endogenous to local policies or other time-varying, local factors that also relate to pollution
- Air pollution is a regional and transboundary problem. Neighbors are affected more even if the treatment is only on the epicenter.

Return

Robustness, Hubei vs. neighbors (1/2)

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
Panel A: Drop firework days					
Post	-0.439***	-0.370***	-0.129***	0.101***	-0.056***
	(0.012)	(0.015)	(0.024)	(0.016)	(0.009)
Post×Y2020	-0.509***	0.181***	-0.225***	0.564***	-0.293***
	(0.014)	(0.019)	(0.025)	(0.018)	(0.013)
Post×Y2020×Hubei	-0.022	0.149***	0.086*	0.101**	0.205***
	(0.049)	(0.047)	(0.047)	(0.041)	(0.042)
Observations	45684	45966	45261	45120	45684
R-squared	0.608	0.500	0.381	0.373	0.385
Panel B: 14 days as post period					
Post	-0.560***	-0.397***	-0.162***	0.088***	-0.046***
	(0.012)	(0.017)	(0.022)	(0.016)	(0.008)
Post×Y2020	-0.363***	0.175***	0.011	0.640***	-0.202***
	(0.014)	(0.018)	(0.018)	(0.019)	(0.011)
Post×Y2020×Hubei	0.061	0.184***	0.107***	0.158***	0.111***
	(0.045)	(0.048)	(0.031)	(0.045)	(0.034)
Observations	34992	35208	34668	34560	34992
R-squared	0.637	0.524	0.341	0.388	0.364

Robustness, Hubei vs. neighbors (2/2)

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
Panel C: Add province by day trend					
Post	-0.593***	-0.370***	0.013	-0.142***	0.087***
	(0.015)	(0.020)	(0.024)	(0.018)	(0.012)
Post×Y2020	-0.508***	0.149***	-0.254***	0.530***	-0.281***
	(0.013)	(0.018)	(0.022)	(0.017)	(0.012)
Post×Y2020×Hubei	-0.041	0.144***	0.071*	0.130***	0.167***
	(0.046)	(0.046)	(0.042)	(0.039)	(0.040)
Observations	48600	48900	48150	48000	48600
R-squared	0.621	0.506	0.390	0.399	0.394
Monitor FEs	Y	Y	Y	Y	Y
Weather	Y	Y	Y	Y	Y
Y2018	Y	Y	Y	Y	Y
DOW FEs	Y	Y	Y	Y	Y

Robustness, neighbors vs. non-neighbors (1/2)

	ln(NO_2)	ln(SO_2)	ln($PM_{2.5}$)	ln(O_3)	ln(CO)
Panel A: Drop firework days					
Post	-0.259***	-0.141***	-0.054***	0.149***	-0.042***
	(0.007)	(0.008)	(0.012)	(0.009)	(0.006)
Post×Y2020	-0.520***	-0.047***	-0.249***	0.264***	-0.249***
	(0.009)	(0.010)	(0.014)	(0.009)	(0.008)
Post×Y2020×Neighbor	0.017	0.226***	0.026	0.284***	-0.043***
	(0.017)	(0.021)	(0.030)	(0.020)	(0.015)
Observations	165816	165675	164265	165111	165111
R-squared	0.587	0.636	0.406	0.379	0.424
Panel B: 14 days as post period					
Post	-0.371***	-0.151***	-0.096***	0.178***	-0.067***
	(0.008)	(0.009)	(0.011)	(0.009)	(0.006)
Post×Y2020	-0.374***	0.015	-0.098***	0.251***	-0.132***
	(0.009)	(0.010)	(0.010)	(0.009)	(0.008)
Post×Y2020×Neighbor	0.033**	0.179***	0.109***	0.364***	-0.062***
	(0.016)	(0.021)	(0.021)	(0.020)	(0.014)
Observations	127008	126900	125820	126468	126468
R-squared	0.619	0.654	0.432	0.395	0.442

Robustness, neighbors vs. non-neighbors (2/2)

	$\ln(NO_2)$	$\ln(SO_2)$	$\ln(PM_{2.5})$	$\ln(O_3)$	$\ln(CO)$
Panel C: Add province by day trend					
Post	-0.434***	-0.100***	0.001	0.026***	0.024***
	(0.009)	(0.010)	(0.013)	(0.008)	(0.006)
Post×Y2020	-0.529***	-0.041***	-0.264***	0.224***	-0.228***
	(0.009)	(0.010)	(0.012)	(0.009)	(0.008)
Post×Y2020×Neighbor	0.018	0.184***	0.010	0.289***	-0.055***
	(0.016)	(0.021)	(0.027)	(0.019)	(0.014)
Observations	176400	176250	174750	175650	175650
R-squared	0.603	0.649	0.422	0.394	0.431
Monitor FEs	Y	Y	Y	Y	Y
Weather	Y	Y	Y	Y	Y
Y2018	Y	Y	Y	Y	Y
DOW FEs	Y	Y	Y	Y	Y

Return

Mechanism: Number of reporting firms

	Number of firms reporting NO_x	Number of firms reporting SO_2	NO_x	SO_2
	Panel A: Hubei		Panel B: Non-Hubei	
Post	0.016	-0.141	-7.704*	-6.564
	(1.760)	(1.793)	(4.100)	(4.091)
Post×Y2020	-34.969***	-35.813***	-16.034***	-17.398***
	(2.489)	(2.535)	(5.798)	(5.786)
Y2020	27.952***	29.857***	31.110***	31.838***
	(1.894)	(1.930)	(4.414)	(4.404)
Observations	100	100	1000	1000
R-squared	0.829	0.836	0.828	0.829
Province FEs	Y	Y	Y	Y
DOW FEs	Y	Y	Y	Y

Mechanism list

Mechanism: Emissions from reporting firms

	$\ln(NO_x)$	$\ln(SO_2)$	$\ln(NO_x)$	$\ln(SO_2)$
	Panel A: Hubei		Panel B: Non-Hubei	
Post	0.008	-0.194**	-0.081***	-0.021**
	(0.055)	(0.078)	(0.010)	(0.010)
Post×Y2020	-0.203**	-0.038	-0.202***	-0.195***
	(0.091)	(0.123)	(0.014)	(0.014)
Y2020	-0.627***	-0.962***	-0.137***	-0.069***
	(0.080)	(0.113)	(0.011)	(0.011)
Observations	985	1013	59734	60432
R-squared	0.642	0.838	0.661	0.780
Firm FEs	Y	Y	Y	Y
DOW FEs	Y	Y	Y	Y

Mechanism list